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THE GEOLOGICAL SIGNIFICANCE AND GENETIC CLASSIFICATION OF ARKOSE DEPOSITS[1]

DONALD C. BARTON

Arkose has been held by different geologists to be significant respectively of several different types of conditions at the time of its formation. By Walther,[2] for instance, it is considered to be so distinctive of desert formations as to be, next to salt deposits, the the most important index of the desert origin of a formation. Mackie,[3] although not mentioning arkose by name, in his discussion of the significance of fresh feldspar in sediments seems to consider the rock especially characteristic of deposits that have formed under rigorous climatic conditions. Von Hauer[4] believes that arkose is especially characteristic of coal-bearing formations. Shaler[5] is of the opinion that it is formed when a granitic terrane, long under moist temperate climatic conditions, is exposed to more rigorous conditions or to marine or lacustrine transgression. Mansfield[6] believes, on the other hand, that the conditions for the formation

[1] Portion of a thesis accepted in partial fulfilment of the requirements for the degree of Doctor of Philosophy at Harvard University.

[2] J. Walther, *Das Gesetz der Wüstenbildung*, 2d ed., p. 174.

[3] William Mackie, *Trans. Edin. Geol. Soc.*, VII (1898), No. LV.

[4] Franz von Hauer, *Die Geologie*, 1875.

[5] W. S. Shaler, *U.S.G.S. Monograph XXXIII*, 1899, pp. 50–55.

[6] G. R. Mansfield, *Bul. Mus. Comp. Zoöl. Harvard*, XLIX (1906), 293–94.

of arkose are intermediate between these extremes, and that a moderately cool and arid climate such as would prevail at moderately high altitudes in the lee of high mountain ranges or in continental interiors would more probably be suitable. The present paper is an attempt to delimit the significance of arkose.

The fundamental conditions essential for the formation of arkose[1] are: (*a*) a granitic terrane, (*b*) conditions favorable to the disintegration of the granite or gneiss with but slight accompanying decomposition, and (*c*) conditions favorable to the erosion and deposition of the débris of disintegration with merely slight loss of the feldspar. In the investigation of the regions which today can supply débris of disintegration for the formation of arkose (Figs. 1 and 2), it was found that disintegration is much more widespread than is perhaps usually realized, and that it takes place in marked amounts under practically all the conditions under which a granitic terrane is exposed (see Table I, a list of the occurrences of disintegration which have been observed by the writer, or which he has been able to find described in the literature, together with a tabular view of the conditions under which the disintegration is taking place). The investigation of the conditions under which the disintegrated material could be eroded and deposited as arkose seems to show that in some cases the conditions favorable to the disintegration are likewise favorable to contemporaneous erosion and deposition of the disintegrated material as arkose, as, for instance, in desert regions, and that in other cases erosion can take place only after some change of conditions, as, for example, a change from the conditions of a moist temperate climate to those of a semi-arid climate. In yet other cases, erosion may take place contemporaneously with disintegration but be followed by decom-

[1] Arkose by original definition and according to most general usage is a rock formed of the relatively undecomposed débris of granite or of rods of granitic mineralogical composition. It may be thought, however, that the original definition should be extended to cover feldspathic clastics derived from the disintegration of syenites, diorites, gabbros. Feldspathic clastics of this type, however, should be rare, since there are practically no purely syenitic, dioritic, or gabbroic terranes, and since the plagioclase feldspar of the diorites and gabbros is more or less readily decomposed. No specimen of this type of feldspathic clastic has been seen by the writer, and only one or two reputed occurrences are reported in the literature.

TABLE

Tabular View of the Occurrences of Disintegration and of the C

Locality	Lat.	Long.	Topography	Elevation	Situation of Disintegration	Depth to Which Disintegration Extends	Depth to Which Decomposition Extends	Amoun comp Shown tegrat
S.E. Ireland	53 N.	7 W.	Mature to old	Under 2,000 ft.	...	...	...	...
Dartmoor, England	51 N.	4 W.	Old	1,500 ft.	General	6 to 15 ft.	3 to 8 ft. Locally some hundreds of feet	Consid
Forez, France	45 N.	4 E.	Old	1,500 ft.	General	10 to 30 ft.	1 to 4 ft.	Noticea thou very
Plateau Central, France	46 N.	3 E.	Old					
Morvan, France	47 N.	4 E.	Old	1,500 ft.	General	5 to 25 ft.	1 to 4 ft.	Noticea thou very
Hohkönigsburg, Vosges Mts., Alsace	48 N.	7 E.	Mature	1,500 ft.	General	8 to 20 ft. plus	1 to 4 ft.	Noticea thou very
Heidelberg Sheet	49 N.	9 E.	Mature	800 ft.	General	5 to 10 ft.	1 ft.	Noticea thou very
Adlersberg, Thüringerwald	51 N.	11 E.	Late maturity	2,000 ft.	...	5 to 8 ft.	1 to 2 ft.	Noticea thou very
Grimsel Pass, Alps	47 N.	8 E.	Young, glaciated mountains	6,500 ft.	Only valley seen	Superficial	...	Very sl
Mer-de-Glace, Alps	46 N.	7 E.	Surface of alpine glacier	5,500 ft.	Surface	Superficial	...	Very sl
Aswan, Egypt	24 N.	32 E.	Shallow young valley	400 ft.	General	Superficial, locally 10 ft.	None	For the very
Pyramids of Gizeh, Egypt	30 N.	31 E.	Pyramids on a plateau	Less than 400 ft.	Surface of the pyramids	2/3 cm.	...	Very sli
Sinai	30 N.	34 E.	Rugged	...	Valley sides	Partly superficial	...	Very sli
Bushmanland, S. Africa	30 S.	20 E.	...	...	...	Superficial	...	Very sli
Himalayas	34 N.	76 E.	Young, mountainous	Above 14,000 ft.	Exposed surfaces	Superficial	...	Very sli
Ceylon	8 N.	80 E.	Mountainous	...	General	Few feet	Slight	...
Lung-wang-shan, China	41 N.	124 E.	Mountainous	...	Rolling valley in mountains	"Tiefgreifend"	Slight	...
Around Inland Sea, Japan	38 N.	138 E.	High coast hills	...	General	...	Slight	Very sli
Mt. Chocorua, N.H.	44 N.	71 W.	Mature, mountainous	3,500 ft.	Summit and flanks of mountain	Mostly superficial	...	Very sli
Jackson, N.H.	44 N.	71 W.	Mature, mountainous	700 ft.	Valley	5 ft. plus	Slight	Noticea thoug
Rockport, Mass.	43 N.	71 W.	Glaciated peneplain	100 ft.	Chiefly shown in glacial boulders	Superficial	...	Noticea thoug
Sykesville, Md.	39 N.	77 W.	Old	400 ft.	Surface generally	30 ft. plus and minus	15 ft.	...
Washington, D.C.	39 N.	77 W.	Old	50 ft.	Surface generally	20 to 80 ft.	Considerable	Conside surfac plete
Richmond, Va.	37 N.	77 W.	Old	50 ft.	Surface generally	10 ft. plus	5 ft. plus	Conside surfac plete
Georgia	34 N.	84 W.	Old	1,200 ft.	Surface generally	Incipient decay to 350 ft. (around Atlanta)	95 ft.	Conside surfac plete
Iron Mt., Mo.	37 N.	91 W.	Old	1,200 ft.	Surface generally	20–80 ft.	20 to 80 ft.	Conside surfac plete
Mt. Stuart, Wash.	47 N.	121 W.	Ruggedly mountainous	9,470 ft.	Summit and exposed portions of flanks	Superficial	...	Slight
Wasatch, Utah	40 N.	111 W.	Ruggedly mountainous	6,000 ft.	Oldest moraine at base of range	20 ft.	Slight	Slight
Butte, Mont.	46 N.	112 W.	Rugged maturity	6,000 ft.	General	20 ft. plus and minus	Slight	Slight
Pike's Peak, Colo.	39 N.	105 W.	Monadnock and peneplain	9,000 ft. 14,000 ft.	Summit and plateau	30 ft. in places; superficial in others	Slight	Slight
Globe District, Arizona	34 N.	111 W.	Rugged maturity	6,000 ft.	...	Superficial	Slight	Slight
California: Sierra Nevada, Sierra Madre	34 N.	119 W.	Ruggedly mountainous	Above 6,000 ft.	Higher slopes	...	Slight	Slight
Lower California	29 N. 31 N.	115 W.	Mountainous	...	...	...	Slight	Slight
Valparaiso, Chile	33 S.	72 W.	Rugged	Less than 1,000 ft.	On ridge	...	...	Slight
Sao Francisco, Brazil	9 S.	40 W.	...	...	...	100 ft. to 300 ft. 60 ft. average	...	Noticea surfac plete

ABLE I

the Conditions under Which the Disintegration Is Taking Place

Amount of Decomposition Shown by Disintegrated Rock	Vegetative Covering	Summer Temperature			Winter Temperature			Rainfall			Remarks
		Max.	Min.	Mean	Max.	Min.	Mean	Yearly	Monthly		
									Summer	Winter	
....	Grass and brush	....	....	57 F.	....	....	....	50 in.	4 in.	5 in.	
Considerable	Heather and moss	68 F. (Mean max. July)	....	60 F.	....	38 F. (Mean min. Jan.)	43 F.	60 to 80 in.	4 in.	5 in.	Medium-grained granite
Noticeable though not very advanced	Grass and woods	95 F. (Mean extremes)	....	64 F.	....	7 F.	36 F.	32 in.	4 in.	3 in.	Coarse porphyritic granite; fine-grained granite not affected
Noticeable though not very advanced	Grass and woods	About the same			About the same as above			....	....	....	Coarse and porphyritic granites; fine-grained granite not affected
Noticeable though not very advanced	Forest	....	....	64 F.	....	....	34 F.	70 in.	....	....	Coarse, porphyritic granite
Noticeable though not very advanced	Forest	....	....	64 F.	....	....	34 F.	60 in.	....	....	Coarse, porphyritic granite
Noticeable though not very advanced	Forest	....	....	....	....	2 F.	32 F.	....	....	....	Medium-grained granite
Very slight	Light or none	(Rigi-Kulm)		39 F.	....	....	....	....	....	....	Medium-grained gneissic granite
Very slight	None	....	....	....	....	....	....	....	....	....	Medium-grained gneissic granite
For the most part very slight	None	112 F. (Mean extremes)	72 F.	93 F.	90 F.	45 F.	62 F.	0	0	0	Coarse, porphyritic, biotite granite
Very slight	None	104 F.	64 F.	82 F.	75 F.	39 F.	55 F.	1.5 in.	0	0.3 in.	Coarse, porphyritic, biotite granite
Very slight	None	....	....	....	....	....	....	Less than 10 in.	....	....	
Very slight	None or very light	....	....	51 F. (Coldest month)	82 F. (Warmest month mean)	....	....	Less than 10 in.			
Very slight	None	....	....	....	....	....	....	....	....	....	
....	Forest	....	....	82 F.	....	....	80 F.	Over 50 in.	$\frac{1}{4}$ in June–July, $\frac{1}{4}$ in Oct.–Nov.		
....	None	....	....	75 F.	....	....	10 F.	30 in.	....	....	
Very slight	Light forest	....	....	75 F.	....	....	32 F.	85 in.	7 in.	9 in.	
Very slight	Mostly none; some forest	....	....	....	....	....	....	....	....	....	Medium-grained pyroxene granite
Noticeable though slight	Forest and grass	....	....	....	....	....	....	....	....	....	Medium-grained, with a slight amount of biotite
Noticeable though slight	Lichens	100 F. (For Boston)	45 F.	65 F.	70 F.	−13 F. (For Boston)	65 F.	45 in.	3 to 4 in.	3 to 4 in.	Medium- to coarse-grained granite; hornblende granite
....	Grass and forest	See Washington			....	....	....	....	....	....	Fine-grained biotite granite
Considerable; at surface complete	Grass and forest	104 F.	36 F.	75 F.	78 F.	−15 F.	34 F.	41 in.	3 to 4 in.	3 in.	Moderately fine mica granite
Considerable; at surface complete	Grass and forest	See Washington			....	....	....	....	....	....	Medium-grained mica granite
Considerable; at surface complete	Grass and forest	100 F.	55 F.	75 F.	73 F. (For Atlanta)	−8 F.	44 F.	49 in.	3 to 4 in.	5 in.	Fine- to medium-grained, porphyritic mica granite
Considerable; at surface complete	....	105 F.	45 F.	75 F.	76 F.	45 F.	74 F.	40 in.	4 in	2 to 2.5 in.	
Slight	Light	....	....	....	....	....	....	....	....	....	Medium-grained granodiorite
Slight	Light	94 F.	33 F.	60 F.	....	....	....	....	....	....	
Slight	Light	94 F.	33 F.	60 F.	58 F.	−29 F.	24 F.	13 in.	1 in.	0.8 in.	Medium to coarse-grained mica, hornblende, quartz monzonite
Slight	Light	....	....	37 F.	....	....	6 F.	30 in.	1.5 to 4 in.	1.2 to 2 in.	Coarse to coarse and porphyritic granite
Slight	Grass and woods and light	117 F.	64 F.	90 F.	80 F.	22 F.	50 F.	17 in.	4 in.	....	
Slight	Light	....	....	....	....	....	....	Very light	....	....	Granodiorite
Slight	Light	....	....	....	....	....	....	Very light	....	....	Granodiorite
Slight	Light	80 F. (Mean extremes)	44 F.	52 F.	....	....	62 F.	29 in., $\frac{2}{3}$ in June and July			Fe-bearing minerals decomposed
Noticeable; at surface complete	....	88 F.	72 F.	76 F.	....	....	82 F.	12 in.	0 in.	1 to 2 in.	

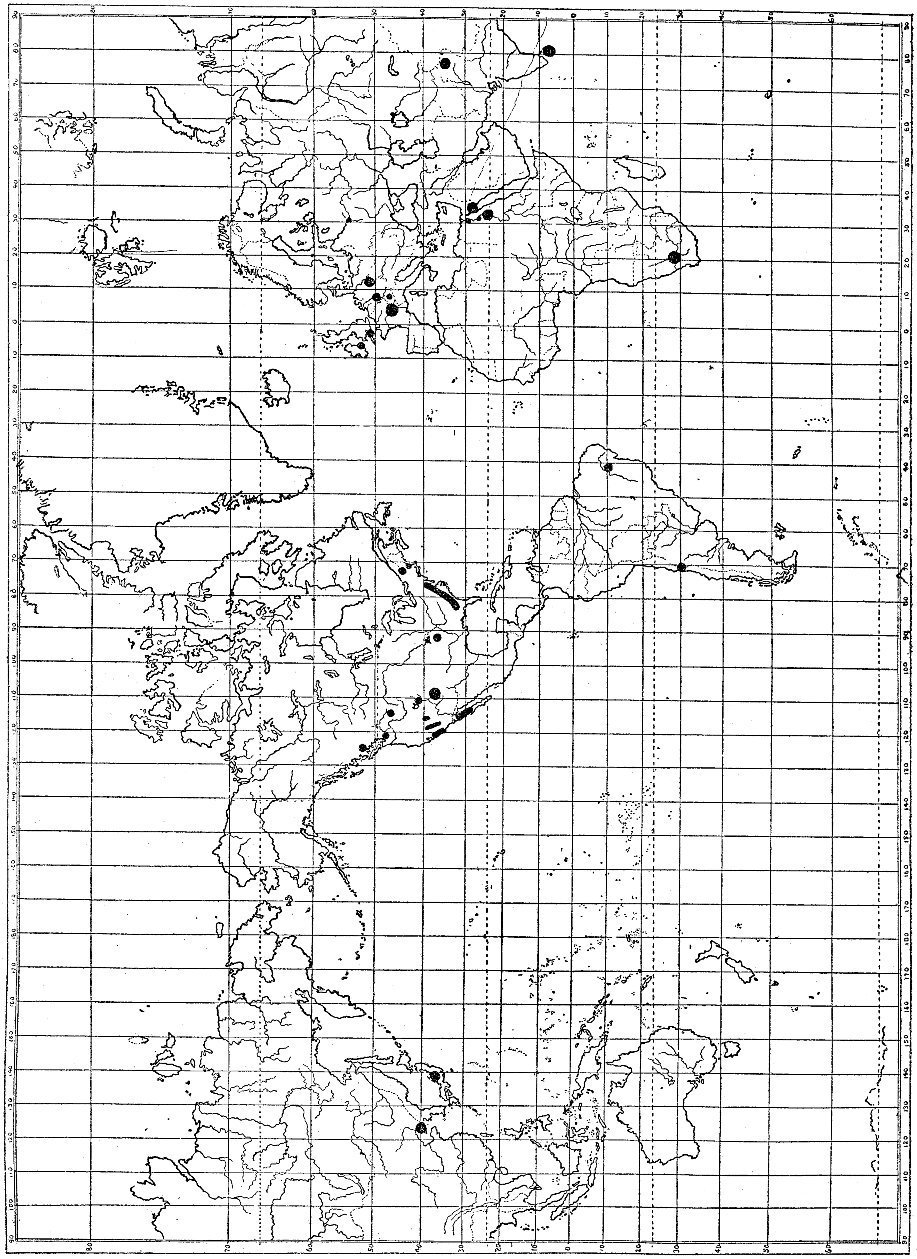

FIG. 1.—Distribution of the occurrences of marked granular disintegration as reported in the literature or observed by the writer.

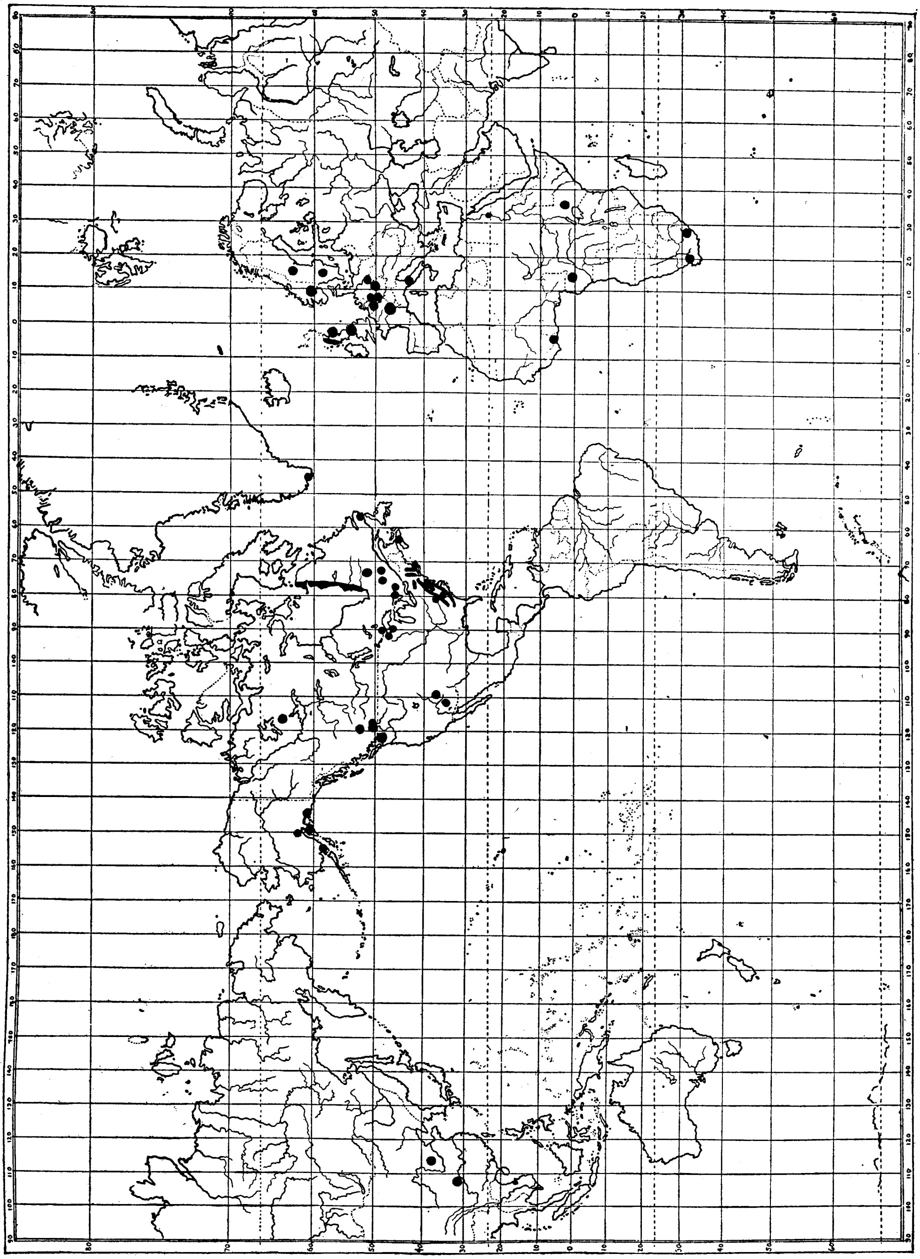

FIG. 2.—Occurrence of arkose deposits as reported in the literature or observed by the writer.

position of the feldspar, with the consequent loss of the material as a possible source of arkose. It was therefore found impossible to limit the significance of arkose to significance of any one or two special sets of conditions. The arkose deposits forming under the different conditions should expectedly be of certain characteristic types, which as a matter of fact agree with the types of arkose deposits as they are found (see Table II). The genetic classification of arkose deposits which appears in the following pages is therefore intended to embrace these various types of arkose deposits.

GENETIC CLASSIFICATION OF ARKOSE DEPOSITS

Arkose deposits may be divided broadly into two classes: (*a*) those formed directly through the effects of rigorous climatic conditions; and (*b*) those formed, at least indirectly, through the effects of moist and more temperate climatic conditions. The latter conditions allow much decomposition, which, however, commonly takes place at a slower rate than the disintegration. The arkose formed directly or indirectly under these conditions therefore has feldspars showing considerable decomposition, has in many cases a matrix of argillaceous material derived from the more easily decomposed grains of feldspar and other silicates, and is associated with beds of argillaceous material derived from the totally decomposed portions of the rock. The former conditions are unfavorable to decomposition, and the arkose deposits forming under them have comparatively unaltered feldspars, have little or no argillaceous matrix, and are not associated to any great extent with argillaceous beds. The distinction, however, is not absolute. At Aswan, Egypt, in a region in which no rain is recorded over a period of many years, the disintegrated granite in some places shows marked decomposition, and the feldspar of modern arkose deposits in the beds of the wet-weather streams of the region is deeply decomposed. In regions of moist, temperate climate it is not uncommon, on the other hand, to find below the zone of complete disintegration a zone of rock which to the eye seems fresh but which crumbles readily under blows from the hammer, and from this rock, within a region of moist, temperate climate, it would be possible for arkose with relatively fresh feldspar to form.

TABLE II

TABULAR VIEW OF THE OCCURENCE, CHARACTER, AND ASSOCIATIONS OF THE ARKOSE DEPOSITS KNOWN TO THE WRITER THROUGH THE LITERATURE OR THROUGH PERSONAL OBSERVATION

Formation and Region	Section	Character of Arkose	Remarks
	NORTH AMERICA		
	PRE-CAMBRIAN		
Hudson Bay (east coast)	Red sandstone and argillite and greywacke 600 ft. Arkose and greywacke 1,000 ft. Arkose	More or less rounded grains and pebbles of quartz and feldspar	Arkose, coarse at base, grading upward
Quebec: Nottaway River, St. Michel, Ranges III, X, XI	With dolomite, quartzite, conglomerate, and greywacke	More or less angular grains of orthoclase quartz and plagioclase	
Copper Cliff arkose, Sudbury, Ont.	Quartzite Greywacke Arkose	Felsitic-looking, interlocking grains, quartz and feldspars	Greywacke well stratified Arkose with little or no stratification
Loraine arkose, Cobalt, Ont.	900 ft. {Quartzite Arkose} Granite		Transition both into quartzite and into the granite
Temiscaming arkose, Nipissing District, Ont.	Arkose Granite	Quartzose and sericitic	Arkose grades into the granite
French River Quad., Ont.	With greywacke, quartzite, dolomite, agglomerate	In heavy bands	Possibly not arkose but tuff
Arkose, quartz slate, Penokee District, Lake Superior	Quartzite Arkose	Quartz, feldspars, mica and fine matrix	Arkose one phase of the quartz slate
Oak Portage	Arkose Sagana granite	Angular quartz and decayed feldspar in fine matrix	
Amnicon Formation, St. Louis River, Wis.	730 ft. {Red shale, grits, sandstone and conglomerate, and arkose}	Grains angular, poorly assorted	Three out of forty-five beds are arkose. Mud-cracks, raindrop prints, cross-bedding

Orienta sandstone, Wisconsin	1,500 ft.	White and red sandstone, brownstone, white and pink sandstone	Quartzose argillaceous	Mud-cracks, raindrop prints, cross-bedding
	1,800 ft.	Brown, red, and white sandstone, grading into arkose		
Belt Formation, Albert Canyon, B.C.		Limestone and argillite Quartzite Arkose Granite	Metamorphosed	Arkose is really a subordinate basal phase of the quartzite
Hotauto conglomerate, Shinumo Quad., Colo.		Limestone		Unsorted
	0.6 ft.	Arkose conglomerate and arkose argillite		
		Quartz diorite		
CAMBRIAN				
Eastern United States:		The base of Cambrian arkosic Georgia to Vermont		
Snowbird Formation, North Carolina	300–2,500 ft.	Conglomerate with arkosic matrix	Moderately rounded quartz and feldspars in a fine-grained quartz-sericite matrix	The arkose is the basal of the quartzite
	900–1,500 ft.	Slate, greywacke, and feldspathic sandstone and limestone		
	350–5,000 ft.	Quartzite with arkose and conglomerate		
		Granite and gneiss		
Hardistonville quartzite, New Jersey		Limestone Quartzite and arkose Granite and limestone	Moderately rounded quartz and feldspar in fine matrix	Arkose a phase of the quartzite
Vermont Formation, Massachusetts and Vermont		Limestone Quartzite Arkose conglomerate Granite and gneiss	Metamorphic	
Labrador: Straits of Belle Isle		Limestone		
	231 ft.	Red and gray sandstone and arkose Arkosic conglomerate		

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
	CAMBRIAN—*Continued*		
Reagan Sandstone, Oklahoma	370 ft. {Grit, sand with green sand, and clay 30 ft. Arkose and quartzite Granite and porphyry	Arkose, coarse	
Bolsa Quartzite, Bisbee, Ariz.	Quartzite with arkosic matrix and phases Granite and gneiss		
	SILURIAN		
Littleton, N.H.	150–500 ft. Dev. argillite 200–300 ft. Arkose 200 ft. {Limestone and slate Limestone 2–80 ft. Arkose and quartzite Granite-gneiss	Basal arkose, granitic in appearance, feldspars and quartz in fine matrix Upper arkose finer, more uniform, becomes quartzitic at top	Basal arkose grades into the granite Faint stratification
	DEVONIAN		
Igaliko sandstone, Greenland	Sandstone 30–40 ft. Reddish and greenish arkose Granite	Granitic in appearance	The arkose is a basal phase of the sandstone
	CARBONIFEROUS		
Narraganset Basin	> 100 ft. Sandstone and shale, arkose and coal and conglomerate < 100 ft. Red shale < 100 ft. Arkose Granite	Basal arkose, sometimes granitic, more often quartzose Fine matrix—coarse Upper arkose fine-grained quartzose with fine matrix, both gray in color	Locally arkose grades into granite—massive or much cross-bedded — interbedded with the red shale, which has raindrop prints and sun-baked surfaces

Rockwell Formation, Meadow Branch Mts., W.Va.	540 ft.	Arkose, sandstone, and shale with thin coal beds	Coarse, gray	Arkose basal phase of the Carboniferous
Myers Shale, Meadow Branch Mts., W.Va.	60 ft.	Red shale Arkose	Coarse, gritty, reddish-gray	Arkose cross-bedded
Horton Series, Nova Scotia		Arkose Granite and sediments	Medium and fine-grained, granitic in appearance, micaceous gray	Arkose with red shale intercalations carrying plant-fossils
		PERMIAN		
Cutler Formation, Colo.	1,500 ft. (total) 215 ft. (arkose)	Reddish Sandstones Arkose, grits, conglomerates, shale, and limestone	Quartzose and reddish	Part of the "Red Beds." Cross-bedding common
Fountain Formation, Colo.	500–1,500 ft.	Rough arkose grading into conglomerate, shale, and sandstone—all red	Coarse, rough, reddish	Part of the "Red Beds." Cross-bedding common
		TRIASSIC		
Sugar Loaf Arkose, Connecticut River, Mass. and Conn.		Sandstone Shale Arkosic sandstones and conglomerate with shale—base arkose Granite and gneiss	All rocks reddish Arkose varies from arkose conglomerate to granitic arkose and to arkosic grits Matrix of argillaceous material	All beds but shale much cross-bedded. Shale with mud-cracks, raindrop prints, reptile tracks, etc.
Stockton Arkose, N.Y., N.J., Md.	1,800–3,600 ft. 2,300–3,100 ft.	Argillite Reddish and yellowish to gray sandstone with some red shale and arkose and conglomerate at the base	Same as Sugarloaf arkose	Same as Sugarloaf arkose Arkose in thick beds or lenses

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
	TRIASSIC—*Continued*		
Tackahoe Group, Richmond Coal Basin, Va.	500 ft. Coarse sandstone (often feldspathic) 2,000 ft. Black shale with gray sandstone 500 ft. {Coal, black shales, feldspathic sandstones 0–300 ft. Sandstones, shale Arkose Granite	Granitic in appearance Angular grains quartz and feldspars in fine-grained matrix Upper arkose reddish Main arkose gray	Arkose occurs not only at base but in beds at nearly all horizons. Cross-bedding common
	JURASSIC		
Skwenta Series, Alaska	Tuffs, slates, and arkose	Fine-grained, dark-green, massive	
Terra-cotta Series, Alaska	Impure limestones, slates, and diorite-arkose		
Naknek Series, Alaska	Arkose and conglomerate	Coarse to fine, hard and massive, in thick beds	Marine fossils in the arkose
	COMANCHEAN		
Patuxent Formation, Atlantic Coastal Plain	350 ft. Sand, arkose, and clay; granite	Decomposed	Fossil plants present
	CRETACEOUS		
Tordrillo Series, Alaska	Black and carbonaceous shales with limestone, sandstone, and arkose		Plant remains in the arkose and in the shales
Holiknuk Series, Alaska	Alternating sandstone and limestone, shale and arkose	Shale and arkose carbonaceous locally	Plant remains and ripple-marks in the shale and the arkose
Oklune Series, Orca Series, Alaska	Very similar to the preceding		

Paysaten arkose, Mt. Hozomeen, B.C.	3,000 ft. 7,100 ft. 1,400 ft. 300 ft. 3,500 ft. 200 ft. 1,500 ft. 100 ft. 1,100 ft. 600 ft. 10,000 ft.	Gray to black argillite Gray to green feldspathic sandstone with black argillite lenses Coarse conglomerate Argillite Green feldspathic sandstone Coarse conglomerate Gray to green feldspathic sandstone Conglomerate Feldspathic sandstone Red argillite and sandstone Massive arkose Volcanic agglomerate Granodiorite	Light-gray, medium-grained, granitic in appearance; angular grains of feldspars and quartz with no matrix; feldspar fresher than in most arkose	Arkose shows little variation in character and little stratification. Plant fossils at two horizons
		EOCENE AND OLIGOCENE		
Kettle River Formation, Phoenix, B.C.		Conglomerate, coarse and fine sandstone, carbonaceous shales, and arkose	Quartzose	
Swank Formation, Yakima Valley, Washington	3,500–5,000 ft.	Arkose, carbonaceous shales, sandstone with arkose or conglomerate at the base		
Puget Formation, Puget Sound, Washington	5,500 ft.	Sandstone and arkose with shale and coal beds	Arkose variable in different layers—some granitic in appearance, some grading into sandstone, bluish-gray in color	All the beds carbonaceous Formation is thinly bedded and with much cross-bedding
Kenai Formation, Alaska		Sandstone, shale, and conglomerate, with coal seams Arkose Quartz diorite	Arkose in part granitic in appearance	

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
	EOCENE AND OLIGOCENE—*Continued*		
Controller Bay region	2,500 ft. Shale and sandstone with coal, arkose, and conglomerate		The different rocks are in monotonous repetition
	EUROPE		
	PRE-CAMBRIAN		
Torridonian sandstone, Scotland	3,000–4,000 ft. Red and gray sandstone and flags, dark shales 5,000–8,000 ft. Red arkose with rare red shales 500 ft. Red sandstone and mudstone with dark shale breccia at base 7,200 ft. In Skye, gray, and buff arkose Lewisian gneiss	Upper arkose (Applecross) granitic in appearance, composed of moderately rounded to well-rounded grains of fairly fresh feldspar and quartz with no matrix	Arkose massively bedded and almost always cross-bedded Dreikantes and raindrop prints occasionally present The arkose is very uniform throughout
Sparagmite, Norway	>5,000 ft. Red arkose and sandstone with breccia, quartzite, and conglomerate	Subangular to moderately well-rounded grains of fresh feldspar and quartz	Similar to Torredonian arkose
Jotnian, Angermanland	White or yellow quartzite with brown shale and with conglomerate Arkose Granite		
	CAMBRIAN		
Scandinavia	Sandstone grading into arkose at base Arckaean crystallines		

		DEVONIAN		
Gedinnian Formation, Ardennes and Eifel districts	10–300 ft.	Shales and sandstones Arkose and sandstone, thin conglomerate	Sericite meta-arkose Quartz grains partially rounded	Bedding even Arkose in beds 3–5 ft. thick. Associated beds with marine fossils
Old Red sandstone, Great Britain			Some granitic in appearance, some conglomeratic Color, pink to red Feldspar fresh	Several phases of the Lower Old Red Sandstone would seem to be arkose
		CARBONIFEROUS		
Berghaupten, Baden	300 ft.	Interbedded arkose, coal, shale, and conglomerate Granite and gneiss	Arkose granitic in appearance, often coarse, sometimes fine, massive, carbonaceous	Coarse cross-bedding common Carbonized plant remains in arkose
Baden-Baden, Baden		Small basin much similar to the preceding		
Hinterohlsbach Basin				
Openau, Baden				
Hohengeroldseck, Baden	130 ft. 90 ft.	Arkose with coal and sandstone Brown micaceous sandstone Coarse arkose Gneiss		
Relsen Coal Basin		Red and white sandy clay Arkose Clay Sandstone Black argillite Arkose Argillite		
Braunau and Kalna Formations		Arkose, reddish sandstone and shale and marl		
Riesengebirge				
Kladrio-Rakonitzer Coal Basin		Base of coal measures sandy slate and arkose		

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
	CARBONIFEROUS—*Continued*		
Laach, Vosges Mts.	210 ft. Grayish arkose with fine conglomerate 6 ft. Coarse conglomerate 18 ft. Small bed of coal Grayish arkose Gneiss	In part granitic in appearance; subangular grains quartz and much kaolinized feldspar in fine matrix	Carbonized plant remains in the arkose
Erlenbach and Weiler, Vosges Mts.	Arkose of similar character and relations		Thought to be a delta deposit
Lower Rotliegendes and Upper Carboniferous, Ottweiler, Rhine Province	Conglomerate and feldspathic sandstone Black shale and yellow, fine-grained sandstone Shale and sandstone with coarse conglomerate Gray sandstone and shale with a little coal Reddish arkose, shale, and feldspathic sandstone Gray shale Red sandstone and shale	Quartzose, grains subangular, matrix about 20 per cent	Stratification rough; beds roughly 3 ft. thick, cross-bedding common Very similar to arkose of Triassic of Massachusetts, New York, and New Jersey
Yorkshire Coal Field, England	In coal measures	Granitic in appearance; color bluish or grayish	Irregularly bedded; much cross-bedding
Flint Ruthin and Mold, England		Gray in color; granitic in appearance	
	ROTLIEGENDES		
Cuseler and Tholeyer Beds, Saar and Nahe District, Germany	Reddish feldspathic sandstone, arkose, shale, and conglomerate with rare gray shale and limestone	Quartzose; feldspar now decomposed	Roughly bedded; cross-bedding common

Tholeyer Beds, Mainz Basin, Germany		Red arkose with red shale, sandstone, mudstone, and marl	Quartzose; feldspar now completely decomposed	Arkose is in massive, even layers, with rare cross-bedding Lithologically very similar to arkose of the Triassic of Massachusetts, Connecticut, New York, and New Jersey
Heidelberg, Germany		Tuffs Arkose and tuffs Granite	Coarse and granitic in appearance	
Baden-Baden, Germany		Red sandstone, shale conglomerate with arkose Black and variegated shale Arkose and variegated shale Granite		
Oppenau, Black Forest		Arkose with dark shales, sandstone, and conglomerate		
Lebach beds, Schramberg, Black Forest	100 ft.	Alternating gray arkose and shale		Plant impressions in the shale
Schöpfheim, Black Forest		Feldspathic sandstone with arkose and dolomite Reddish shales, mudstones Conglomerate, arkose, and sandstone	Quartzose, red feldspar now completely kaolinized	Stratification rather even, massive. Facetted pebbles possibly present
Trienbach beds, Vosges Mts.	90 ft. 60 ft. 60 ft.	Purple shale with arkose intercalations Gray arkose with shale Arkose with conglomerate granite, schist, or Erlenbach beds	In part very granitic in appearance	Plant fossils present
Kohlbachel beds, Vosges Mts.	540–600 ft.	Reddish arkose, shales, conglomerate, and breccia	Quartzose	The arkose is only a local phase of the sandstone

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
	ROTLIEGENDES—*Continued*		
Thuringia Forest	Conglomerate, shale, sandstone, arkose, and breccia Granite	Coarse, gray, with fine matrix	The arkose is a basal phase, but is not derived from the underlying granite
	TRIASSIC		
Morvan district, France	Limestone and gypsum 30 ft. Arkose and marl 90 ft. Arkose with clayey intercalations Granite	Quartzose and heavily silicified, constituent grains showing much rounding; fine-grained silicified matrix	Lower arkose in massive, even beds at the base, with thin shale beds toward the top with reptile tracks
Rémilly, near Dijon	Somewhat similar arkose, possibly the equivalent of the preceding arkose		
Aubenais, Ardecke Chessy, near Lyons Rhaetic beds Bunt Keuper beds Franconia	600 ft. Sandstone, grading into arkose in the Palatinate at Parkstein and vicinity 150 ft. Red argillite 60 ft. Sandstone, locally feldspathic Dolomitic arkose, limestone, reddish clay, and marl Sandstone, clay, marl, and arkose	Mostly very quartzose with or without much matrix	The deposits, especially of the arkose, are supposed by Thürach to be shore deposits
	TERTIARY ARKOSE		
Stampian Beds Sannoisian beds Limagne, France	Marls and limestone Arkoses, sandstones and marls, grits (Sandy clays, limestone and basal arkose in southern part of the basin only) Granite	Coarse to fine, in part very granitic in appearance, usually with more or less argillaceous matrix	Arkose is in more or less massive beds; rarely there is some cross-bedding

Basin of Lembron Basin of Forez France	Arkose deposits similar to the preceding and probably equivalent to them		
	ASIA		
Yang-Tzi Province	Tillite (Cambrian) 150 ft. { Coarse sandstone and conglomerate Arkose and conglomerate } Granite		
Wu-t'ai System	Pelites Psammites Arkose T'ai-shan gneiss	Much metamorphosed	
Alwar Formation, India	Quartzite with basal arkose		
Araveli Group, India	Gneiss, schist, and quartzite		The gneiss is believed by Oldham possibly to represent arkose
Bawar Formation, India	Limestone and carbonaceous shales Quartzite and arkose Granite	In parts granitic and very similar in appearance to the underlying granite	
Eocene beds, Upper Indus	Heterogeneous sandstones and conglomerates, possibly with some arkose		
	AFRICA		
Congo Series, Matjé's River, Cape Colony		Coarse, granitic in appearance, matrix of quartz and sericite	
Congo Series, French Hoek, Cape Colony	Limestone Arkose and feldspathic grits Conglomerate Granite	Granitic in appearance	Locally the arkose grades into the granite

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
AFRICA—*Continued*			
Nieuwerust Series, Cape Colony	Dark shale and sandstone Arkosic conglomerate with shale and sandstone Gneiss		
Black Reef Series, Cape Colony	Quartzite and slate Arkose and conglomerate Granite		
Gold Coast	Arkose with clayey and pebbly beds	Reddish grit with angular grains	
Carboniferous and Devonian, French Congo	Arkose, whitish sandstone and dolomitic layers Greenish and reddish shales and calcareous sandstones Arkose Crystalline schists		
Lake Rudolf, British East Africa	Grauwacke and arkose Crystalline schists	Reddish, quartzose with fine matrix	
Nubian sandstone	Argillaceous sandstone and conglomerate Arkose Granite	Very granitic in appearance	Faint stratification possibly present in upper part of the arkose; the arkose grades into the granite
AUSTRALIA AND SOUTH AMERICA			
No account of arkose either in Australia or in South America has come to the notice of the writer			

A. ARKOSE DEPOSITS FORMED ENTIRELY UNDER RIGOROUS CLIMATIC CONDITIONS

Feldspar showing merely slight decomposition.[1] Argillaceous material absent or present in minor amounts.[2]

1. *Deposits formed in desert regions.*—The deposits are massive, homogeneous, and in some cases of very large size. In desert regions, the disintegration takes place chiefly on outcrops directly exposed and not protected, as in moist temperate regions, by a mantle of vegetation. The débris of disintegration is easily eroded and the processes of erosion and disintegration and deposition of the eroded, disintegrated material as arkose can therefore take place contemporaneously, and can continue as long as the desert conditions persist and as long as the granitic terrane remains unburied. The size of an arkose deposit formed under such conditions will therefore depend chiefly on the size of the terrane of disintegration, the size of the basin of deposition, and the length of time the desert conditions prevail. The constancy of the conditions during the period of formation should be marked by a massiveness and homogeneity of the deposits.

a) Terrestrial: In deserts, wind action prevails the greater part of the time, but rare storms do occur and in the short space of their existence do an immense amount of work. Deposits of arkose formed in desert regions therefore are likely to be in part of eolian and in part of aqueous origin. The arkose shows in part the eolian characteristics of well-rounded sand grains, faceted pebbles, local lag-gravels, dune stratification, etc., and in part the ordinary characteristics of water action. In deposits of arkose forming in arid mountain regions, the greater part of the transportation of the disintegrated material may be by water action, during the rare cloudbursts, and by the streaming of the débris down the hill slopes under gravity. The constituent grains in this case are subangular, and quartz and feldspar grains should be present in about the same proportions as in the original granite or gneiss, since the amount of

[1] At the time of formation of the arkose. Subsequent exposure may produce complete decomposition.

[2] The possibility of the presence of exotic material brought in by a river whose headwaters lie in a temperate or tropical region should not be forgotten.

transportation undergone should not be sufficient to cause marked comminution and loss of the feldspar. The deposits as a whole should be rather massive, but with cut-and-fill stratification rather common, and with considerable intercalation of coarse block débris toward the sides of the valleys.

An example of this type of deposit is found in the Applecross group of the Torridonian sandstone, a pre-Cambrian formation extensively developed in the Northwest Highlands of Scotland. The ideal section of the Torridonian sandstone is given by the Geological Survey[1] as shown in Table III. The Applecross group

TABLE III

Groups	Thickness	Composition	Chief Occurrence
3. Aultbea....	3,000–4,000 ft.	Sandstone, flags, dark and black shales, and calcareous bands passing down into chocolate and red sandstones, and gray micaceous flags with parting of gray and green shale	Loch Ewe and Loch Broom
2. Applecross..	5,000–8,000 ft.	Chocolate and red arkose with pebbles of quartzite, quartz-schist (felsite, jasper, etc.), and occasional red and chocolate shales	Cape Wrath to Skye
2. Diabaig....	500 ft. in Gairloch; 7,000 ft. in Skye	At top, fine red sandstone with red mudstone and gray shale; at base, coarse breccia of Lewisian gneiss. In Skye, gray and buff arkose in great thickness	Assynt to Skye

is a formation composed of massive arkose of very uniform character (Fig. 3), marked off by thin intercalations of fine quartzitic and shaly sandstone into persistent layers of rather uniform thickness—in each case three, six, or ten feet or so. Although extremely massive in texture, the arkose shows most irregular stratification and almost invariably is strongly cross-bedded. Walther reports cross-bedding indicative of dune formation, and faceted pebbles. The lithologic character of the arkose may be seen from the accompanying photomicrograph. In the finer-grained phases, quartz composes a slightly greater proportion of the whole than in this medium-grained phase (quartz about 60 per cent and feldspar 40 per cent), and the grains

[1] B. N. Peach, J. Horne, and others, "The Geologic Structure of the Northwest Highlands of Scotland," *Mem. Geol. Surv. Great Britain*, 1907.

show a slightly greater degree of rounding. It is notable that the predominant feldspar of the arkose, microcline, does not occur in the underlying terrane. Where the arkose rests directly on the mountainous topography of the underlying terrane, the arkose basally becomes a coarse breccia. One of the most striking features of this formation, with the exception of this basal portion, is its uniformity throughout its great thickness.

To this type of arkose deposit should be referred the following:

The Torridonian Arkose, pre-Cambrian of Scotland.

Arkose of the Sparagmite formation, pre-Cambrian of Scandinavia

Lower Old Red Sandstone, Scotland (in part)

Paysaten Arkose, Cretaceous, British Columbia–Washington

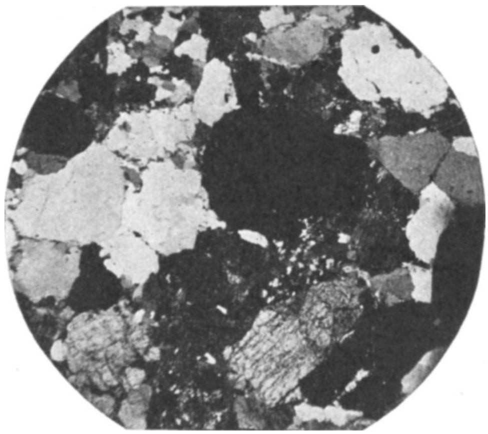

FIG. 3.—Photomicrograph of Terridonian arkose, Applecross, Scotland, showing the lack of matrix in a desert arkose. The rounding of the grains is rather obscured by secondary growth of the grains. Magnification, 15 diameters.

b) Marine: If marine conditions prevail adjacent to a granitic terrane in a desert region, marine arkose may form, having in part the characteristics of an eolian arkose. Some of the constituent grains in this case should show the rounded outlines of eolian sand grains. The deposits as a whole, however, should show the structure and stratification of marine sediments. To this type of deposit should be referred the arkose that is now forming along the east shore of the Gulf of California.

2. *High-altitude deposits.*—Local deposits, of small size and extent. The conditions of high altitude, according to Oldham and others, are peculiarly favorable to disintegration. Erosion of the disintegrated material takes place rapidly, with rapid deposition of it in many cases as arkose in local catchment basins of the intra-mountain valleys. As such a region is subject to general

degradation in the course of time, the deposits must be temporary in character, and usually of recent geologic age. They may be wholly or in part lacustrine, fluviatile, alluvial (cone or fan), landslide, or fluvioglacial. The stratification should be rather irregular, and the constituent grains should be angular to subangular.

To this type of deposit should be referred possibly some of the deposits of the Upper Indus Valley, although from the descriptions of the deposits it is not quite clear whether they are really arkosic or not.

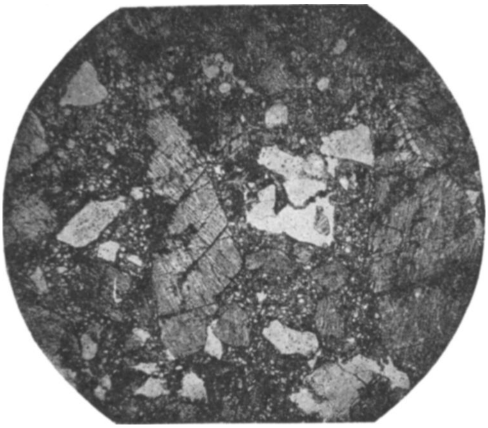

FIG. 4.—Photomicrograph of Pondville (Mass.) arkose, an arkose formed under moist temperate conditions, showing the quartz and feldspar grains in a fine-grained matrix of quartz and argillaceous material. Magnification, 15 diameters.

3. *Deposits of cold (high-latitude, subglacial) climate*.—In the high latitudes, the effects of disintegration are not pronounced, or at least they are not noted in the literature. "Disintegration" is reported many times, but in most cases it is clearly block disintegration that is meant, and in no case has the writer been able to make it out clearly to be granular disintegration. That the effects of the latter are not noticeable may be due in large part to the relatively recent glacial erosion of the products of the preglacial disintegration, or, in regions of considerable relief, it may be due in part to excessive block disintegration and erosion. As the temperature range is often great, and the lower part includes the critical point of freezing, and as, furthermore, hydration can take place at the surface during the summer and, in regions not too far north, at all times below the level of freezing, there would seem to be no theoretical reason why granular disintegration should not take place. Granitic and gneissic blocks exposed on the surface of glaciers in many cases show noticeable disintegration, although

the amount that takes place in this manner is slight. If disintegration takes place, the conditions would seem favorable to the erosion of the disintegrated material and its deposition in arkose deposits of small or moderate size, probably in association with glacial or fluvioglacial beds. To this type of deposit may possibly be referred some of the pre-Cambrian arkose of Canada.

B. DEPOSITS FORMED DIRECTLY OR INDIRECTLY THROUGH THE EFFECTS OF MOIST AND USUALLY TEMPERATURE CONDITIONS

Deposits of small or moderate size; the arkose commonly with a matrix of fine-grained argillaceous material and usually associated with argillaceous beds; feldspars commonly showing a moderate amount of decomposition (Fig. 4).

In the present regions of moist temperate climate, especially where the topography is in a mature or old-age stage of development, there is almost universally present a very considerable accumulation of disintegrated material which is available as a source of material for the formation of arkose. The following section, from the vicinity of Autun, France, in its essential features is characteristic of such regions as the granite terranes of Morvan, the Plateau Central, and Forez, France; the Vosges Mountains, the Odenwald, and the Thüringerwald, Germany; Dartmoor, England; the Piedmont belt and the Pike's Peak region, United States.

1 ft.........	Mantle of vegetation; surface soil and subsoil of gritty brown clay with quartz and feldspar grains
6 ft.........	Granitic sand and gravel, stained with limonite; feldspar showing considerable decomposition toward the surface, the amount decreasing with depth
$2+n$ ft........	Granite more or less fresh on superficial examination, but crumbling under light blows of the hammer; depth difficult to estimate; fresh granite

The relative and absolute proportions of these zones vary greatly. The maximum depth to which disintegration was observed by the writer to have extended was 40 feet, at Royat (Puy-de-Dôme), France, and at Hohkönigsburg, Vosges Mountains. On Dartmoor and in the Piedmont belt decomposition is more in evidence than in France and, in the Piedmont belt especially, the zone of soil and

subsoil is much larger in proportion to the zone of disintegrated material. The rate of disintegration under the conditions of a moist temperate climate seems to be rather slow—in New England there has been since the Glacial Period disintegration sufficient barely to efface the glacial striae and polish on granitic and gneissic ledges—and the very considerable amounts of disintegrated material generally found in those regions are the result of slow accumulation under the protection of the mantle of vegetation. General erosion of this disintegrated material and its subsequent deposition as arkose can take place only when the mantle of vegetation is critically weakened or destroyed. When this has once happened and the mantle of disintegrated material has been swept away, a long time must elapse before considerable amounts of the disintegrated material can again accumulate. The arkose deposits formed from the accumulated débris of disintegration in a moist temperate climate will therefore be of small or moderate size. As the mantle of soil and completely decomposed rock is eroded at the same time as the mantle of disintegrated material, the arkose is commonly associated with mudstones and shales, and, as the disintegration is accompanied by considerable decomposition, the arkose itself is likely to contain much argillaceous material and to have feldspars showing noticeable decomposition. Since stream transportation of débris results in the rather rapid elimination of the feldspars, the arkose is likely to grade into quartzite.

The causes which might critically weaken or overcome the mantle of vegetation and result in the erosion of the accumulated products of disintegration are: introduction of arid or semi-arid conditions, introduction of subglacial or glacial conditions, a marked increase of rainfall, a marine transgression, deforestation by forest fire, and marked upwarping. A marked change of climatic conditions toward aridity in a region previously of moist temperate climate would necessarily result in a marked diminution of the vegetation and in the exposure of the underlying disintegrated material to erosion during the occasional storms. Glacial conditions might result either in the erosion of the disintegrated material by the ice itself or in the exposure of the disintegrated material to erosion through the destruction of the vegetation of the temperate

conditions without the introduction of an arctic flora sufficiently luxuriant to form anew the protective mantle of vegetation. A marked increase of the rainfall, it was suggested by Shaler, might be such that the streams would be competent to waste generally the land surface. A marine transgression would necessarily result in the working over of the materials of the regolith, irrespective of the luxuriance of the mantle of vegetation, and might easily result in the deposition of arkose. Forest fires are not uncommonly due to lightning and often are effective agents of deforestation. It would seem possible that a period of heavy rains following a severe forest fire might result in the general erosion of the mantle of disintegration. Upwarping of considerable amount would result in an increase of the stream gradients, in an increase or decrease of the rainfall, and in the lowering of the mean temperature. The total effect might possibly be conditions favorable to the general erosion of the mantle of disintegration. A very special cause is to be found in volcanic activity of the explosive type, which not uncommonly results in deforestation and desolation in limited local area. Of this type of deposit, in which the arkose should be associated with tuffs, there is at least one example, the Rotliegendes arkose north of Heidelberg, Germany.

In regions of youthful topography and considerable relief in a moist temperate climate, there would seem to be no reason why disintegration should not take place. That it is not seriously in evidence is probably due to the fact that it is masked by block disintegration and by rapid erosion. If it does take place, the débris that can be eroded at one time is of small amount and is lost through decomposition of the feldspars or through intermixture with the heterogeneous stream-borne sediment.

In tropical regions, decomposition commonly prevails over disintegration, but in two localities disintegration is reported as occurring with but slight accompanying decomposition. The débris in these cases, if eroded under normal conditions, would probably be lost through decomposition, but if eroded under the conditions of a marine transgression, or under the conditions of aridity, there would seem to be a strong possibility that a deposit of arkose might be formed. Except by means of a contained fauna or flora, such

deposits would probably be indistinguishable from the corresponding types of deposits of the temperate zone. No deposits have been recognized to be of this type.

1. *Terrestrial.*—(*a*) Deposits laid down under semi-arid conditions: Arkose reddish, composed of subangular iron-stained grains of quartz and partially decomposed feldspar deeply in an iron-stained matrix of fine-grained quartz and of argillaceous material.

When the moist temperate conditions give way to those of aridity, the mantle of vegetation, weakened by the change, is no longer able to protect the accumulated products of decomposition and disintegration, and during the occasional violent storms they are quickly eroded, to be deposited with rapidity usually in the near-by valleys and catchment basins. Owing to deposition from torrential streams, the materials of the mantle of disintegrated material are laid down in coarsely stratified banks and lenses of arkose, showing much foreset and cut-and-fill cross-bedding. The soil and mantle of completely decomposed rock are deposited, partially sorted, as cross-bedded, argillaceous sandstones and as more finely and evenly stratified gritty mudstones. As the temporary lakes dry up, these mud beds become sun-baked and glazed and cracked and may receive raindrop prints. Under the conditions of alternate wetness and dryness, there should be almost complete decomposition of organic matter and oxidation of the iron.

Deposits of this type are not rare, and a good example may be found in the Sugarloaf arkose of the Connecticut River Triassic. The formation occurs in what was possibly a Triassic basin, and consists essentially of an unordered alternation and repetition of gritty, argillaceous sandstones, conglomerates, arkose, and sandy and calcareous mudstones. There is a coarse, general stratification whose dip initially was apparently low. In the beds of mudstone, even, fine stratification is the rule, but cut-and-fill bedding is found in a few places. The coarser strata are strongly cross-bedded, mostly with the foreset type of bedding. Cut-and-fill bedding, however, is common. The mudstones show mud-cracks, raindrop prints, glazed surfaces, and reptile footprints. The arkose is found in banks and lenses, chiefly at or near the base, but also at

numerous higher horizons. It is composed of subangular grains of quartz and subangular grains and pebbles of feldspar in a fine-grained matrix of argillaceous material. The color of the whole formation is deep red, due to a heavy stain of ferric iron. Fossils are rare in the formation.

The following deposits are apparently of this type:

Arkose of the Amnicon formation, pre-Cambrian, Wisconsin

Sugarloaf arkose (Triassic), Connecticut River area, Massachusetts and Connecticut

Stockton arkose (Triassic), New York, New Jersey, Pennsylvania

Arkose of the Upper Carboniferous, Ottweiler, Rhine Province, Germany

Arkose of the Lower Rotliegendes, Rhine Province, Germany

Arkose of the Rotliegendes, Mainz Basin, Vosges Mountains and Black Forest, Germany

Arkose of the Old Red Sandstone, England

Arkose of the Cutler formation, Permian, Colorado(?)[1]

Arkose of the Fountain and Lower Wyoming formations (Permian), Colorado(?)[1]

(*b*) Deposits laid down under moist, chiefly temperate, conditions of climate: Arkose grayish, composed of subangular grains of quartz and of considerably decomposed feldspar in a matrix of fine-grained quartz and argillaceous material, in most cases carbonaceous, and in some cases carrying plant fossils; the arkose commonly associated with coal deposits.

The causes of a general erosion of the regolith in a region of moist temperate climate are not completely evident. The suggestion of the introduction of subglacial conditions as a possible cause seems not well founded, since the several glacial epochs of the Pleistocene do not seem to have caused a general erosion of the regolith of the Piedmont belt to the south of the glaciated area. It would seem reasonable to expect, furthermore, that the effect of the change on the mantle of vegetation would be a replacement of the temperate by arctic flora. The suggestion that a marked increase in the amount of the rainfall might be a sufficient cause would likewise seem not well founded, as an increase in the rainfall characteristically results in more luxuriant vegetation, with a consequent increase in the protective power of the mantle of vegetation.

[1] Commonly considered marine, but apparently very like the Newark beds of the Connecticut River and the New York-New Jersey Triassic areas.

Forest fires are another possible cause. They are very commonly due to natural causes and often are effective agents of deforestation. It would seem possible that a period of heavy rains following a severe forest fire might easily result in the general erosion of the regolith. Upwarping of considerable amount, with the consequent increase of stream gradients and lowering of the mean temperature, if associated with decrease in the amount of the rainfall, might possibly result in the general erosion of the regolith.

While these causes are thus in doubt, the fact of the formation of deposits under these general conditions seems to be indubitable. There is a characteristic type of arkose deposit which is usually associated with carboniferous beds or coal, which is itself carbonaceous or may even carry carbonized plant remains, and which therefore must have formed under moist climatic conditions. As the feldspar shows much decomposition, as there is an argillaceous matrix, and as the quartz and feldspar grains are distinctly angular to subangular, the constituent materials of the arkose would seem to have been derived from the débris of disintegration under moist temperate conditions. The arkose, commonly in part, is coarse and granitic in appearance and seems not to have been transported far from the point of origin of its constituent material, and in part usually is finer and less feldspathic, and seems to have been transported for a greater distance. Besides being associated with coal beds, the arkose is associated with conglomerates, impure sandstones, and silty mudstones. Cross-bedding is common, and many of the beds seem to be the result of rather rapid deposition. The color of this type of arkose is gray.

As an example of this type of deposit, there may be taken the arkose of the Richmond (Triassic) Coal Basin in Virginia. The lower portion of the section in the basin is as follows:[1]

Productive Coal Measures	500 ft.	Interstratified beds of bituminous coal, black shale, feldspathic and micaceous sandstones
Lower Barren Beds	0–300 ft.	Sandstones and shales under the coal beds, often with arkose
Boscabel Bowlder Beds	0–50 ft.	Local deposits of bowlders of gneiss and granite

[1] N. S. Shaler and J. B. Woodworth, *U.S.G.S. Nineteenth Ann. Rept.*, Part II (1897–98), pp. 423–26.

The arkosic beds are best developed about the granitic masses of the eastern margin, but reappear from horizon to horizon with increasing marks of waterwear. The arkose of the basal horizons is granitic in appearance, and by the inexpert eye might not be distinguished from the granite. The arkose is gray in color and is composed of subangular grains of quartz and much decomposed feldspar in an argillaceous matrix of small amount. The arkose of the higher horizons is not so granitic in appearance, there is a somewhat lower content of feldspar, and the quartz and feldspar grains are slightly more rounded. Some of the associated shale beds are carbonaceous, and locally there are small intercalations in the arkose of carbonaceous silty material.

To this type of deposit there should probably be referred:

The Carboniferous arkose of the Narragansett Basin, Rhode Island and Massachusetts

The arkose of the Rockwell formation (Mississippian), Meadow Branch Mountains, West Virginia

The arkose of the Vosges Mountains, the Black Forest, and adjacent parts of Bavaria

The arkose of the Coal Measures of the Yorkshire Coal Field, England

The arkose of the Coal Measures of the Flint, Rhutin, and Mold districts, England

The arkose of the Richmond (Triassic) Coal Basin, Virginia

The arkose of the Corwin formation (Jurassic), Alaska

Comanchean arkose at the base of the Coastal Plain series, Maryland, Virginia, North Carolina

The arkose of the Swauk formation (Tertiary), Washington

The arkose of the Puget formation (Tertiary), Washington.

The arkose (Early Tertiary) of the Matanuska and Controller Bay regions, Alaska

c) Deposits formed under glacial conditions: If an ice sheet advances over a granitic terrane in which there is a mantle of disintegration, it would seem possible for small amounts of this débris locally to be preserved as arkose among the various glacial deposits. In New England, there is in several localities deep preglacial disintegration, showing that the mantle of disintegration of the Piedmont district probably extended in former times northward over this area. Arkose is apparently lacking however, in the New England glacial deposits. No example of this type of deposit is known to the writer.

2. *Marine and lacustrine.*—(*a*) The basal member of a new, transgressive marine series is commonly composed of the materials of the former regolith. If the shore forces are not too violent in their working over of the débris, the basal deposit in regions of granitic rocks may be arkosic. The constituent grains show more or less rounding. There may be present a small amount of argillaceous matrix. Through the elimination of the feldspar the arkose may grade into quartzite. Arkose deposits of this type may grade into deposits of the type discussed in (*b*).

To this type of deposit (*a*) there should be apparently referred:

Arkose of the Hotauto formation (pre-Cambrian), Shinumo Quad., Arizona.
The Cambrian arkose of Eastern United States (in large part)
The arkose (Silurian) of Littleton, New Hampshire (in part)
The arkose of the Igaliko formation (Devonian), Greenland
The arkose (Triassic) of the Morvan (in part), France
The arkose (Tertiary) of the Limagne (in part), France

(*b*) When erosion of the mantle of disintegration in a granitic terrane adjacent to the sea or to a lake occurs, deposition of the disintegrated material is likely to take place in the sea or lake with, as a consequence, the formation of arkose. Near the shore the arkose is in banks and lenses and is interstratified with beds composed of the material from the soil and zone of decomposition and of argillaceous material eliminated from the débris of disintegration. The constituent grains of the arkose are subangular to poorly rounded, the degree of rounding being greater in the more quartzose beds. There may in some cases be a slight amount of argillaceous matrix. Unless the feldspar is itself reddish, the arkose is grayish in color. Although not necessarily basal, the arkose is more likely to be near the base of the formation than not, since the change of conditions which causes the erosion of the mantle of disintegration is likely to mark the inauguration of a new period of sedimentation. The arkose formed far from shore is less granitic in appearance than that formed immediately at the shore, there is considerable rounding and sizing of the constituent grains, and there is elimination of much feldspar and argillaceous material. The arkose in many cases grades into quartzite.

An example of this type of deposit is the Tertiary arkose of the Limagne, France. During the Oligocene times the Limagne was

first a brackish-water basin some thirty km. in width and later a fresh-water lake lying then as now in the granite plateau of the Plateau Central. The arkose is found chiefly near the base and is found in banks alternating with greenish marl and in some cases extending out a considerable distance from the edge of the basin. Some of the arkose, especially that at Royat, is massive, coarse, composed largely of good sized fragments of the coarse phenocrysts of the underlying granite, and is extremely granitic in appearance. The greater part of the arkose, however, is much finer, is more quartzose, is composed of more-rounded grains, and grades into quartzite. There is in some cases an argillaceous matrix, in some cases a sericitic matrix, and, in some of the more quartzose phases, there is very little matrix. There is a general even horizontal stratification. Where cross-bedding is present in individual strata it is usually of the simple foreset type.

To this type of deposit are probably to be referred:

Much of the pre-Cambrian arkose of Ontario
Arkose of the Congo Series, French Hoeck, Cape Colony
The Cambrian arkose, North Carolina–Tennessee
Fitch Hill arkose, Silurian, Littleton, New Hampshire
Haybes arkose and Weismes arkose (Devonian) Ardennes–Eifel District
Arkose of the Grés bigarrés and Grés vosgien (Triassic) of the Morvan region, France
Dolomitic arkose (Keuper), Franconia and Thuringia
Arkose of the Blasensandstein and Coburgerbausandstein (Keuper), eastern Palatinate
Lower Stampian–Sannoisian arkose (Oligocene), Limagne, Forez, and Roannais basins, France
Much of the Jura–Cretaceous arkose of southwestern Alaska
Arkose of the Cutler formation (Permian), Colorado(?)
Arkose of the Fountain and Lower Wyoming formations (Permian), Colorado(?)

C. UNTRANSPORTED OR SEDENTARY ARKOSE

Basal, unstratified deposits grading into the underlying granite. When deposition begins in a district, the original regolith locally may be buried before it has been eroded to any considerable extent. It is thus possible for arkose to be formed without the usual intermediate steps of erosion, transportation and deposition of the

disintegrated material. The arkose is composed of the constituent minerals of the granite or gneiss in essentially their original proportions. Some of the silicates, especially the biotite, hornblende, and plagioclase, are in many cases highly decomposed. The constituent grains are angular. The upper part of the arkose may show a rude stratification and may grade upward into a well-stratified deposit. The lower portion is massive and grades downward into the granite, and may show the unaltered cores of bowlders of exfoliation.

A good example of this type of arkose is to be found in the lower arkose in the Silurian at Littleton, New Hampshire. Between the Niagaran Limestone and the granite there is from two to eighty feet of arkose which is coarse and granitic in appearance. The quartz and feldspar are the same as those of the underlying granite and are present in practically their original proportions. There is a slight amount of a fine-grained dark matrix. In its upper portion, the formation shows faint traces of stratification and in its lower portion it grades into the underlying granite-gneiss. Locally the original spheroidal weathering and the unaltered cores and shells of concentric weathering are distinguishable.

To this type of deposit are to be referred:

The arkose (in part) of the Vermont formation (Cambrian), Massachusetts and Vermont
The basal arkose (Silurian) at Littleton, New Hampshire
Pre-Cambrian arkose (in part) of the Cobalt District, Ontario
Basal arkose, Narragansett Basin, Massachusetts and Rhode Island
Nubian arkose, Aswan, Egypt

D. SUMMARY

The geological significance of arkose in brief, then, varies from case to case and cannot be limited in the general statement to significance of a special set of conditions. Each deposit is significant of some special set of conditions and these in many cases can be determined from the individual deposit or its associations. In the preceding discussions an attempt has been made to show a grouping of these in conformity with a genetic classification of arkose, each type of which is significant of some special type of

conditions. But even if the premises of this classification should be seriously disputed, it still remains a fact that most formations lying unconformably on a former granitic terrane have arkose at or near the base, and there seems to be a more or less general rule that, whenever a period of deposition is inaugurated over a granitic terrane, arkose is the first or one of the first deposits to be laid down, whatever the prevailing conditions. This basal arkose commonly shows but slight effects of wear and is apparently near the point of origin of its constituent material. At higher horizons, there often is yet other arkose, in most cases showing more signs of wear and apparently having been transported for a greater distance; and in still other cases, as has been noted, arkose composes the whole of a formation, thousands of feet in thickness. The deposits are of such differing types and have such different associations with coal measures, with mud-cracked red beds, with beds containing faceted pebbles, and with beds carrying marine fossils, that the old conception of the limited significance of arkose is manifestly incorrect, and arkose must be significant of several types of conditions.